

Synanthropisation of coastal vegetation in southern Spain

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Abstract. Coastal dunes have a high ecological value but are often damaged or overexploited by beach tourism. The main problems for the vegetation of this ecosystem are the physical destruction and the synanthropisation, the latter due to colonisation by alien and apophyte species favoured by human action. This study determines the synanthropisation of the vegetation of a stretch of coastline in southern Spain, based on the floristic analysis of six habitats: upper beach, foredune, mid-dune, back-dune, creek and rocky area. The percentage of synanthropic species was 51%; 33% were apophytes, mainly ruderal species and weeds, and 18% were alien species, mostly from gardens adjacent to the coastal zone. The degree of synanthropisation varied for each habitat, with a marked increase from the beach inland: nil on the beach and up to 63% on the back dune. Richness and diversity were higher in habitats with greater synanthropisation, but at the cost of less naturalness. Land protection has ensured the physical conservation of the vegetation but is not preventing increased colonization by alien species, some of them with high invasive potential. Measures must be taken to protect coastal vegetation from destruction and synanthropisation.

Keywords: synanthropisation, alien plants, ruderal plants, native plants, coastal vegetation, vegetation protection.

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Introduction

Coastal dunes are ecosystems of high ecological value but fragile and often overexploited by beach tourism (Carboni *et al.*, 2009; Tordoni *et al.*, 2018; Kuroda & Sawada, 2019; Sarmati *et al.*, 2019). An indicator of their value is the inclusion of most coastal habitats in the European Union (EU) Directive 92/43/EEC, as EU interest habitats and in the European Red List of Habitats, such as the Mediterranean coastal dune grassland (B1.4b), endangered and present in southern Spain (Janssen *et al.*, 2016).

The main causes of coastal vegetation disturbance are the construction of houses, hotels, parking lots and tracks, trampling by visitors and vehicular traffic (Hylgaard & Liddle, 1981; Andersen, 1995; Kutiel *et al.*, 2000; Lemauiel & Rozé, 2003; Martínez *et al.*, 2004; Santoro *et al.*, 2012; Malavasi *et al.*, 2013; Šilc *et al.*, 2017; Kuroda & Sawada, 2019; Giulio *et al.*, 2020; Zhang *et al.*, 2020). Significant consequences of these threats are the physical destruction of vegetation and synanthropisation; the greater the accessibility of the area and the fragmentation of vegetation, the greater the degradation and synanthropisation (Muñoz *et al.*, 2011; Farris *et al.*, 2013).

Synanthropisation is a process of alteration of the vegetation as a consequence of direct or indirect human impacts, which favors the colonisation of alien species,

sometimes invasive, and of apophytes, native species not specific to the colonised habitats but favoured by human action and by his tendency to expand (Faliński, 1975; Kornaś, 1982; Olaczek, 1982).

Alien species are less functionally diverse than native species. Among them, species that are invasive have a capacity to spread, reducing the physical space left for native species and driving the plant community towards functional homogenisation, favoured by changes in climatology, such as rising temperatures already occurring in the Mediterranean; as a consequence, synanthropic species proliferate, and there is a loss of native species (Carboni *et al.*, 2010; Tordoni *et al.*, 2019; Del Vecchio *et al.*, 2021).

The synanthropisation of coastal vegetation is leading to a progressive loss of habitats with good conservation status. For example, García-Mora *et al.* (2001) found that only 13% of dunes sampled in the southwest of the Iberian Peninsula had a low vulnerability and Kutiel (2001) reported that 17% of coastal dunes had good or reasonable ecological status in Israel. Synanthropisation of coastal habitats is a global problem, reported, for example, in Australia (Batianoff & Franks, 2000), Europe (Giulio *et al.*, 2021), Italy (e.g. Acosta *et al.*, 2007; Carboni *et al.*, 2010; Ciccarelli, 2014; Del Vecchio *et al.*, 2015), Spain (e.g. Campos *et al.*, 2004; Asensi *et al.*, 2014) or Ukraine (e.g. Dubyna *et al.*, 2010; Kolomiichuk & Maltseva, 2014).

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In Spain, vegetation protection against physical destruction (such as urban planning constraints) has improved greatly, although some threats remain, such as the construction of access paths and beach bars or the mechanical cleaning of beaches. However, there is no control over synanthropisation, which leads to progressive degradation of natural habitats, and even the disappearance of some species; sometimes the degree of synanthropisation is so high that coastal habitats are barely recognizable. As Sperandii *et al.* (2020) point out for Italy, nominal protection is not effective if it is not accompanied by effective management, conservation and monitoring measures.

In the study area, a stretch of coastline in southern Spain, despite anthropic pressures (especially urban development and beach tourism), there is still a strip of dune system preserved by urban constraints, where natural vegetation is apparently well preserved. However, the actual conservation status is unknown. The aim of this study is to analyze this strip of coastal vegetation by assessing the degree of synanthropisation of the different habitats, from the upper beach to the back dune, to

determine whether the current protection is enough for the conservation of coastal habitats.

Materials and methods

Study area

The study area is located in the municipality of Tarifa, in the province of Cadiz (Andalusia), in southern Spain. It is a stretch of the Atlantic coast, 23 km north of Tarifa Cape, in the Strait of Gibraltar (Figure 1, left). The site comprises an area covered by natural coastal vegetation between the bare ground of the beach and the existing buildings inland (Figure 1, right). The elevation ranges between 3.5 and 10 m asl. The length of the site is 1,915 m, with an area of 214,817 m², resulting in an average width of 112 m. The coordinates of the extremes (in ETRS89 datum) are north end 36°7'10.31''N, 5°49'59.18''W (UTM 245013, 4000924); and south end 36°6'13.97''N, 5°49'27.73''W (UTM 245749, 3999165).



Figure 1. Study area. Left: Location. Right: Delimitation on orthophoto.

The climate of the area is Mediterranean, with an average annual temperature of 18.6°C, stable year-round (average maximum 21.6°C, average minimum 15.4°C) and annual rainfall of 523 mm, with a marked period of summer drought, with very little or almost no rainfall between June and August (8 mm on average in the three months).

Habitats

Coastal dunes can be divided into different zones according to their geomorphology and vegetation. Six habitats have

been considered in this study, defined according to broadly established criteria, and also according to the possibility of their precise physical delimitation on the ground. The habitats considered were:

- Upper beach. Narrow strip on the upper beach with widely scattered plants between the bare ground of the beach and the foredune. This area should be much larger under natural conditions, but tourist pressure on the beach, both from visitors and beach cleaning, has reduced it to a small, heavily endangered strip.

- Fore-dune. Dune partially stabilized by vegetation, although with mobility on the front bordering the upper beach. The substrate is loose beach sand. This unit includes the embryonic dune and the mobile dune, but it is not possible to delimit them precisely on the ground. Some characteristic plants may occur in the embryonic dune but with irregular distribution; the floristic composition is often indistinguishable from the fore-dune.
- Mid-dune or transition dune. Flat area between the fore-dune and the back-dune, with transitional vegetation. The substrate is more compact than the fore-dune, with incipient soil formation.
- Back-dune or fixed dune. The presence of coastal scrub and a lesser presence of psammophilous plants mainly characterises it. The substrate is still beach sand but consolidated, with soil formation and little wind mobility of edaphic materials.
- Small creeks cross the area, draining both natural runoff and drainage from gardens and built-up areas. They are visible on the back and mid-dune but disappear before reaching the beach.
- Contact between rocky areas and fore-dune. At the southern end of the study area, the mid and back dune disappear, and the fore-dune comes into contact with a rocky slope; it is not a cliff, but a steep slope with coastal scrub and rocky outcrops.

Plant classification

Plant nomenclature has followed the International Plant Names Index (IPNI, 2021). The main groups of Kornaś (1990), widely accepted, were used to classify the plants (Table 1); the lower categories, based on vague criteria according to Pyšek (1995) and difficult to delimit, were not applied.

Table 1. Plant classification according to the origin and human action. Source: Kornaś (1990).

Native	Present in the natural coastal vegetation without the concurrence of human action, although occasionally may be favoured by it.
Synanthropic	Present in the natural coastal vegetation thanks to human action, with intentional or unintentional introduction.
Apophytes	Native to the region but not in the natural coastal vegetation, where their presence is due to human action.
Antropophytes (aliens)	Not native to the region, introduced voluntarily or involuntarily, sometimes escaped from cultivation and eventually naturalized.
Archaeophyta	Introduced before 1500 A.D.
Kenophyta	Introduced after 1500 A.D.

Within alien species, we have differentiated the region of origin (continent) firstly, and secondly,

the introduction path, using in the latter case three categories: (i) Gardens: ornamental species planted in gardens close to the study area, which escape and become naturalised; (ii) Crops: species currently or formerly cultivated, which have become naturalised in the area; (iii) Indeterminate: alien species whose origin in this area is uncertain, often accidentally introduced or expanded from distant or past introductions.

We consider alien plants to be naturalised in a conventional meaning, according to Richardson *et al.* (2000), i.e. when they reproduce and maintain populations without direct human intervention but do not necessarily invade natural vegetation. Pyšek *et al.*, (2004) propose a minimum of 10 years without direct human intervention to consider a plant naturalised, but this is not an objective criterion; for example, *Pontaderia crassipes* began to invade in Spain a few years after its introduction without reaching a decade. Invasive plants are naturalised plants that have the potential to spread over a large area (Pyšek *et al.*, 2004).

Data collection

Strip transects were used to sample the area (Burnham *et al.*, 1980; Melville & Welsh, 2001). For the main transects, a crossed design was used (Buckland *et al.*, 2007), with perpendicular strips running NW-SE direction (parallel to the sea) and NE-SW (from the sea inland). Sixteen transects were conducted from the beach inland (or vice versa), and seven transects parallel to the sea, one along the upper beach, two along the fore-dune, two along the mid-dune and two along the back-dune. A transect was also conducted along each of the four creeks detected. Finally, two more transects were carried out in the rocky areas at the southern end. The objective was to achieve the maximum sampling density, so no truncation in the width of the strips was established; however, a detection width on each side of the transect axis (w) of 2 m for herbaceous plants, 4 m for low shrubs and up to 10 m for shrubs and trees was estimated. Consequently, the estimated sampling density was 100% for tree and shrub species, and at least 50% for low bushes and 25% for herbaceous vegetation.

The boundaries between habitats were delimited during the walks, using orthophotos and GPS. This information was incorporated into a geographic information system (GIS) to map the habitats and calculate the area, length and average width of each unit.

All species observed along transects were recorded, although detailed relevés were carried out at each habitat change in transects perpendicular to the sea and every 200 m on transects parallel to the sea. Shorter transects in creeks and rocky areas were treated as a single relevé. For each species detected, the abundance and habitat in which it occurred were recorded. Plant abundance was established according to the Braun-Blanquet (1932) scale. The overall abundance value for each species per habitat was calculated by averaging all observations.

Data analysis

Once the floristic composition of the habitats was established, several analyses were carried out. Firstly, a category was assigned to each of the species recorded: native (N), apophyte (Ap) or alien (Al). The synanthropisation index (Jackowiak, 1990; Chmiel, 1993) is the ratio of apophyte and alien species to the total number of established species: $I_s = (Ap + Al) / (N + Ap + Al)$. It has been calculated for the whole flora, and for each habitat. This index has been widely used, among others, in several studies on coastal vegetation (e.g. Dubyna *et al.*, 2010; Kolomiichuk & Maltseva, 2014; Valcheva *et al.*, 2019).

The proportion of alien species was also calculated, named by some authors as anthropophytization index (Dąbkowska & Sygulska, 2012; Jaźwa & Stadnicka-Futoma, 2015; Ziaja & Wójcik, 2015): $I_{AN} = Al / (N + Ap + Al)$. For alien species, we also analysed their origin, introduction path, life form (following Raunkiaer, 1934), category (archaeophytes or kenophytes) and family.

Habitats were subjected to a hierarchical clustering (HC) and a non-metric Multidimensional Scaling (nMDS), using the Bray-Curtis (1957) index, according to the proportion of native, apophyte and alien species. The results were represented by a dendrogram in the HC and a scatter plot in the nMDS. To assess the adequacy of the results, we calculated the cophenetic correlation coefficient (Sokal & Rohlf, 1962) of the HC (the closer to 100% the tighter the HC) and the stress for the nMDS, using the formula number 1 of Kruskal (1964), whose results were assessed according to the author's proposal (Table 2).

Table 2. Evaluation of Kruskal's stress.

Stress	Kruskal's definition
>20%	Unlikely to be of interest
15-20%	We must still be cautious
10-15%	We wish it were better
5-10%	Satisfactory
<5%	Impressive

Changes in synanthropisation related to the distance to the beach were analysed for the four habitats distributed continuously along the study area parallel to the sea (upper beach, foredune, mid-dune and back-dune).

Habitats were analysed according to their floristic composition, also performing HCs and nMDSs. Two different indices were used in this case, the Jaccard (1908) similarity index, which relates the number of exclusive species to the number of shared species, and the Bray-Curtis (1957) dissimilarity index, which measures the total difference in species abundance between two sites, divided by the total abundance at each site; the former only takes into account the presence or absence of species, and the latter also their abundance.

Two scenarios were analysed, the current floristic composition of the habitats (native and synanthropic species, both apophyte and alien) and the composition excluding the synanthropic species (native flora only). The results have been represented by dendrograms and scatter plots, and their adequacy has also been calculated using the cophenetic correlation coefficient and the Kruskal's stress.

Finally, we calculated several indices of richness, diversity and evenness, in the two previous scenarios, native and synanthropic species and only native species. We recorded the number of species (S) and calculated the indices of Shannon and Weaver (1949) –applying neperian logarithms–, Pielou (1966) and Simpson (1949). Table 3 shows the criteria used for the interpretation of these indices.

All calculations were performed using PRIMER 7 software (PRIMER-e, Quest Research Limited, Auckland).

Table 3. Interpretation of indices

Index	Interpretation
Shannon-Weaver (neperian log)	0-2 Low diversity
	2-3.5 Average diversity
	>3.5 High diversity
Pielou's evenness	0 Minimum evenness
	1 Maximum evenness
Simpson	0 Maximum diversity
	1 Minimum diversity

Results

Habitat distribution and extent

Based on the results of the fieldwork, a GIS map of habitat distribution has been produced (Figure 2). For each habitat the area and percentage of occupancy with respect to the total study area was calculated. Taking into account the area of each habitat and its length (parallel to the sea except in watercourses, where the current water line is measured), its average width has been calculated (Table 4).

The most extensive habitat is the fixed dune, followed by the foredune and then the transition zone (Table 4). The rest of the habitats have a restricted presence in the area.

Table 4. Characteristics of the habitats

Habitat	Altitude (m asl)	Area (ha)	Percentage (%)	Average width (m)
Upper beach	3.5-4.0	0.327	1.52	1.85
Foredune	4.0-5.0	6.830	31.79	37.26
Mid-dune	4.5-5.5	5.069	23.60	27.90
Back-dune	5.0-8.0	8.713	40.56	58.40
Creek	4.0-8.0	0.272	1.27	6.50
Rocky area	5.0-10.0	0.271	1.26	10.15
Total	3.5-10.0	21.482	100.00	112.18



Figure 2. Distribution map of the habitats.

Floristic composition of the habitats

As a result of the sampling, 149 plants have been recorded in the study area. The species have been compiled in a table, including their name, category (N, Ap, Al), habitat and abundance (Table S1).

Synanthropisation of the flora

Native species account for 49% of the total (Figure 3). These plants are highly adapted to coastal environments (e.g. *Achillea maritima*, *Cakile maritima*, *Calamagrostis arenaria*, *Calystegia soldanella*, *Crithmum maritimum*, *Crucianella maritima*, *Eryngium maritimum*, *Lotus creticus*, *Marcus-kochia littorea*, *Ononis variegata*, *Pancratium matimum* or *Sporobolus pungens*), with limited or no presence outside these habitats. Some native species are favoured by synanthropisation, such as *Echium gaditanum*.

Synanthropic plants accounted for 51% of the total. Most of them are apophytes (33%), ruderal weeds introduced from nearby crops and as a consequence of disturbance caused by urban development and the opening of pedestrian paths. Although the study area currently borders on built-up areas, these were developed mainly from the late 1990s onwards on former arable land.

There were 27 alien plants, and they accounted for 18%, all of them naturalised, although frequently only with few (or just one) individuals and limited expansion. Alien species were distributed among 19 families, with a maximum of 3 species per family (*Asteraceae* and *Poaceae*). Within life forms (classified according to Raunkiaer, 1934), phanerophytes dominated (55.6%), followed by hemicryptophytes and chamaephytes (14.8% each), therophytes (11.1%) and geophytes (3.7%). Some 26% of the species were succulent. Asensi *et al.* (2016) identified 26 alien species on the southern coast of Spain (including the study area); 12 of them have also been recorded in our study, but 15 other species located by us had not been cited in that work. The most frequent areas of origin of alien species were

Africa (41%), mainly Southern Africa and the Americas (38%), both South and Central-North America, and to a lesser extent Asia (14%) and Oceania (7%).

Most of the alien species (59%) came from nearby gardens, 33% were accidentally introduced or planted in the past and naturalised, and 2 species (8%) came from former cultivation, *Ficus carica*, traditionally planted for its figs, and *Opuntia maxima*, introduced in the past for cochineal production. Among the 27 alien species found, there are 19 whose presence in the vicinity of the study area is limited to the gardens bordering the coastal dune, while there are another eight species that are not associated with these gardens. Considering that the gardens were planted from 2000 onwards, 70% of the current alien plants have entered the area in the last two decades.

Kenophytes predominate. Only *Ficus carica* is clearly an archaeophyte, perhaps the first plant to be domesticated in the Neolithic (Kislev *et al.*, 2006); *Arundo donax* could also be a kenophyte, as the first references in the western Mediterranean date back to the 16th century (Sanz *et al.*, 2004). The latter species is also the only one that is clearly invasive and also a transformer (Richardson *et al.*, 2000). Although naturalised and common, *Agave americana* and *Opuntia maxima* are not invasive in the study area; *Acacia saligna* is locally abundant, but only in wet areas; *Lantana × strigocamara* and *Yucca aloifolia* are recent colonisers, which appear to be expanding; two species (*Aizoon pubescens* and *Nicotiana glauca*) are still sparse, but have great invasive potential; *Carpobrotus acinaciformis* is currently very sporadic, but eradication programmes have been carried out in this coastal stretch (Andreu *et al.*, 2010).

Synanthropisation of the habitats

The composition of vegetation in each habitat was analysed to determine the degree of synanthropisation (Table 6). The upper beach was free of synanthropic species. It was followed by the foredune and rocky areas, although colonisation by some apophytes and alien species was

detected. In the mid-dune native species were reduced by about half and in the creeks, even more. Finally, in the back-dune native species account for just over a third, the rest being apophytes and alien species.

The vegetated area on the upper beach occupies a narrow strip at the foot of the foredune, with very low vegetation cover. The only frequent species were *Ononis variegata* and *Silene nicaeensis*, the rest being sporadic. No synanthropic species were detected. The vegetation in this area is affected by trampling, beach cleaning and the construction of beach bars and terraces. A characteristic species of this habitat, *Cakile maritima*, frequent in the area a few decades ago according to our observations, is now very rare.

invasive alien species, and *Avena sterilis*, an apophyte. Among the frequent species (3 or greater in Braun-Blanquet scale), 40% were native (*Echium gaditanum*, *Equisteum ramosissimum*, *Festuca alopecuroides*, *Marcus-kochia littorea*, *Olea europaea* subsp. *europaea*, *Pycnocomon rutifolium*, *Scirpoides holoschoenus* and *Verbascum giganteum* subsp. *martinezii*) and 60% apophytes (*Bromus rigidus*, *Cynara cardunculus*, *Daucus carota*, *Dittrichia viscosa*, *Festuca ambigua*, *Lavatera cretica*, *Plantago bellardii*, *P. coronopus*, *Scolymus hispanicus*, *Silybum marianum*, *Sisymbrium officinale* and *Sonchus tenerrimus*). The less frequent species were almost equally divided between native and synanthropic, while in sporadic species, 32%

Table 6. Synanthropisation of habitats.

Habitat	Native		Synanthropic						Total
			Apophytes		Alien		Total synanthropic		
	Nº	%	Nº	%	Nº	%	Nº	%	Nº
Upper beach	11	100.0	-	-	-	-	-	-	11
Foredune	27	79.4	5	14.7	2	5.9	7	20.6	34
Mid-dune	36	54.5	24	36.4	6	9.1	30	45.5	66
Back-dune	41	37.6	44	40.4	24	22.0	68	62.4	109
Creek	7	41.2	7	41.2	3	17.6	10	58.8	17
Rocky areas	21	72.4	3	10.4	5	17.2	8	27.6	29

In the foredune 34 species were found, mostly native (79.4%). The dominant species were *Calamagrostis arenaria*, *Lotus creticus*, *Orobancha densiflora* and *Pancratium matimum*, followed by *Achillea maritima*, *Crucianella maritima*, *Eryngium maritimum*, *Marcus-kochia littorea* and *Silene nicaeensis*. Less frequent were *Calystegia soldanella*, *Cyperus capitatus*, *Echium gaditanum*, *Medicago marina*, *Ononis variegata*, *Pycnocomon rutifolium* and *Sporobolus pungens*. All dominant species were native, with synanthropic species occurring sporadically.

In the mid-dune native species were reduced (54.5%), with synanthropic species gaining weight (45.5%), especially apophytes. The vegetation was dominated by 3 native species (although favoured by human action), *Echium gaditanum*, *Pycnocomon rutifolium* and *Verbascum giganteum* subsp. *martinezii*, and two synanthropic species, *Plantago bellardii* and *Scolymus hispanicus*; all of them dominated mainly around the paths and trampled areas. A second group of abundant species was dominated by foredune plants such as *Calamagrostis arenaria*, *Festuca alopecuroides*, *Lotus creticus*, *Marcus-kochia littorea*, *Orobancha densiflora*, *Pancratium matimum* and *Silene nicaeensis* as well as other elements such as *Lagurus ovatus* and *Paronychia argentea*. Three synanthropic species, *Plantago coronopus*, *Dittrichia viscosa* and *Festuca ambigua*, and one alien plant, *Arundo donax*, were frequent. Among the sporadic species, the synanthropic dominated (58%).

On the back-dune, the proportion of native species decreased to 37.6% compared to 62.4% of synanthropic species, with a significant weight of alien plants (22%). The dominant species were *Pistacia lentiscus*, native and main coastal scrub-forming plant; *Arundo donax*, an

were native, 37% apophytes and 31% alien. The abundance of alien plants, although scattered, showed that this habitat was the main introductory path from nearby gardens.

The dominant species in the creeks was *Arundo donax*, an invasive alien. It was followed in importance by two native species *Rubus ulmifolius* and *Scirpoides holoschoenus*. Scarcer were some native (*Tamarix africana*, *Typha domingensis*), alien (*Acacia saligna*, *Xanthium strumarium*) and apophyte species (*Rumex crispus*). Among the sporadic species, synanthropic dominated (67%) compared to native (33%).

The rocky areas were dominated by bushes of *Pistacia lentiscus* and *Rhamnus alaternus*, and the contact with the dune by grasslands with *Festuca alopecuroides* and *Pycnocomon rutifolium*, all of them native species. Among the less frequent and sporadic species, the native dominated (68%), especially those typical of foredunes and bushes, compared to the synanthropic species (32%); there was a significant percentage of alien species with sporadic presence.

Considering the percentages of native, apophyte and alien plants, a HC and a nMDS were performed, using the Bray-Curtis index (Figure 3). The cophenetic correlation coefficient for the HC was 79.28%, quite consistent, and the value of Kruskal's stress for the nMDS was 1%, very satisfactory. Two clearly differentiated groups can be observed, one covering the upper beach, foredune and rocky areas, with lower synanthropisation, and the other covering the mid and back dune and the creeks, with greater synanthropisation.

In the four habitats occurring continuously along the study area, distributed parallel to the sea (upper

beach, foredune, mid-dune and back-dune), an inverse distribution of native versus synanthropic species was observed from the beach inland: moving away from the

beach inland the number of native species decreased, while the number of synanthropic species increased (Figure 4).

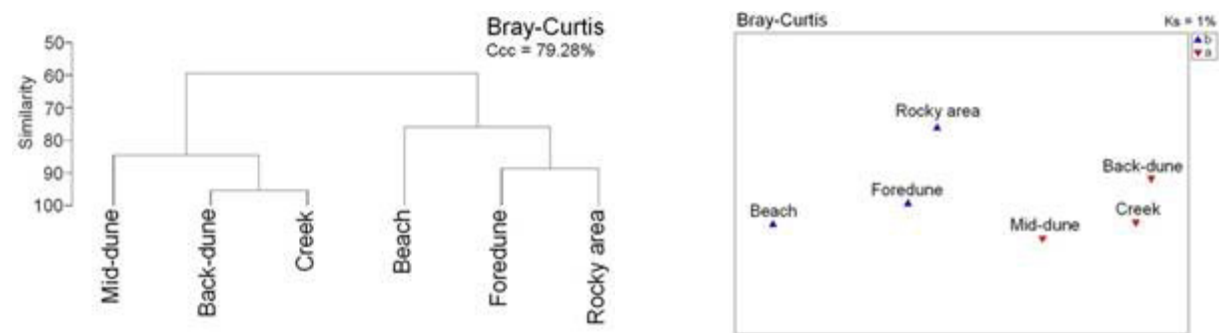


Figure 3. Similarity according to plant categories (native, apophyte and alien) using Bray-Curtis index. Left: Dendrogram. Right: Scatter plot graph. Ccc - Cophenetic correlation coefficient; Ks - Kruskal's stress.

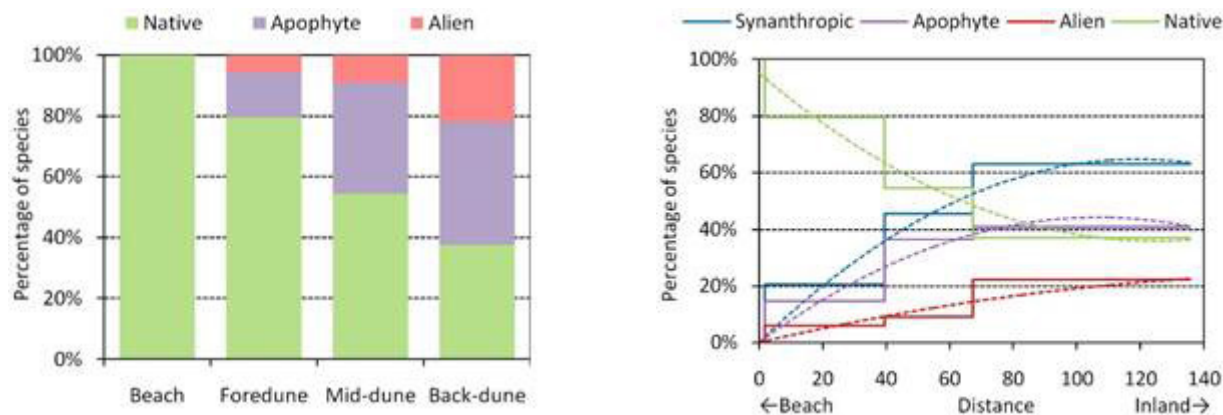


Figure 4. Synanthropisation of the main habitats. Left: Percentages of species per category and habitat. Right: Changes of plant categories related to beach distance.

In order to determine the floristic similarity of the habitats, HCs and nMDSs were performed using the Jaccard and Bray-Curtis indices in two scenarios, the current floristic composition and the composition excluding synanthropic species (Figure 5). The Kruskal stress value in all cases was 1%, very satisfactory. The cophenetic correlation coefficients for the HCs were in all cases consistent, although higher when only native flora was analysed: 85.57% for Jaccard index and the entire flora; 91.75% for Jaccard index and native flora; 89.75% for Bray-Curtis index and the whole flora; and 91.08% for Bray-Curtis index and native flora.

The results showed differences in the distance between habitats, derived from the consideration or not of species abundance and the consideration of the whole flora or only native species. Creeks appeared separated from the rest of the habitats in all cases; they have moisture-dependent azonal vegetation unrelated to the rest of the other plant communities.

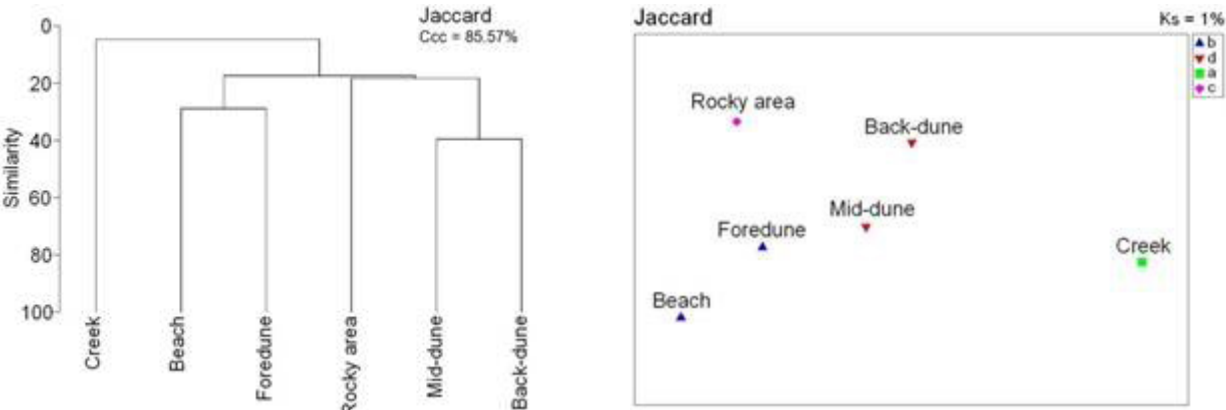
The upper beach is closely related to the foredune when all species were considered, but separated when only native species were considered. The mid and back-dune were closely related when all species were considered; when only native plants were analysed this situation persisted with the Bray-Curtis index, but not with Jaccard index, where the mid dune was closer to the foredune. The rocky areas occupied an independent position, close to the dune system.

Richness, diversity and evenness indices were calculated for each habitat, considering all species currently present and only native species (Table 7). The back-dune presented high species richness, diversity and evenness, as many species had scarce presence. It was followed in richness and diversity by mid-dune. The foredune and rocky areas had somewhat lower diversity and evenness. The upper beach and creeks had the lowest diversity and evenness.

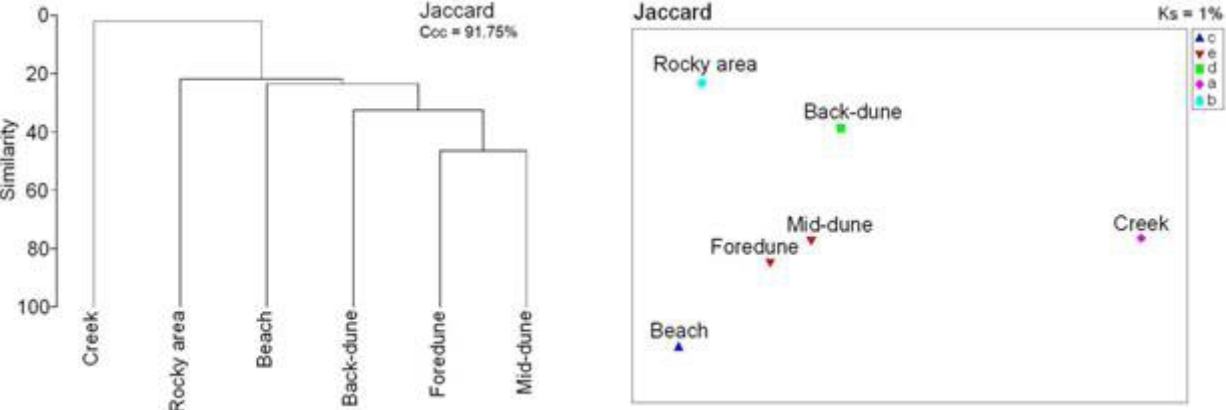
Table 7. Diversity, richness and evenness indices.

Habitat	Species	Species	Pielou	Shannon	Simpson
Upper beach	Native + synanthropic	11	0.79	1.88	0.23
	Native	11	0.79	1.88	0.23
Foredune	Native + synanthropic	34	0.84	3.05	0.06
	Native	27	0.88	2.91	0.07

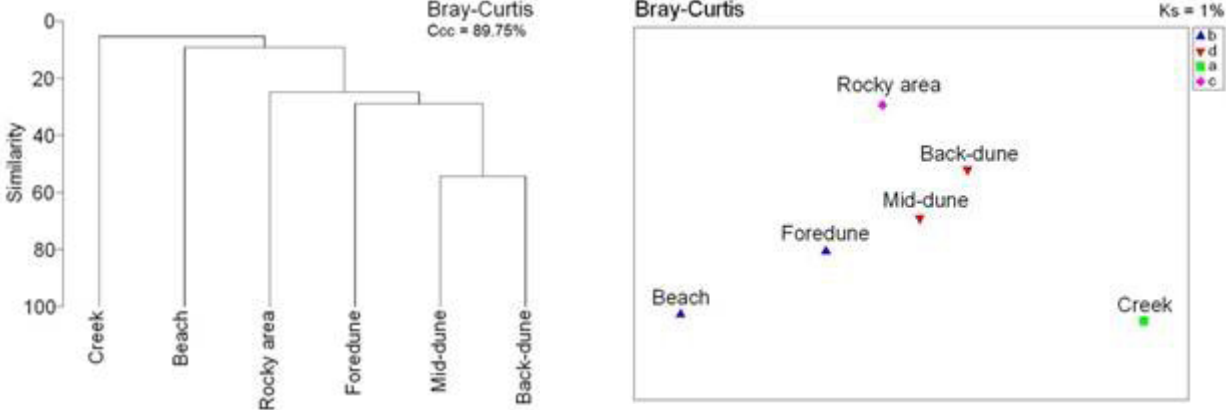
Habitat	Species	Species	Pielou	Shannon	Simpson
Mid-dune	Native + synanthropic	66	0.90	3.76	0.03
	Native	36	0.90	3.24	0.05
Back-dune	Native + synanthropic	109	0.90	4.23	0.02
	Native	41	0.90	3.29	0.05
Creek	Native + synanthropic	17	0.83	2.35	0.12
	Native	7	0.79	1.54	0.26
Rocky areas	Native + synanthropic	29	0.87	2.95	0.07
	Native	21	0.86	2.62	0.09



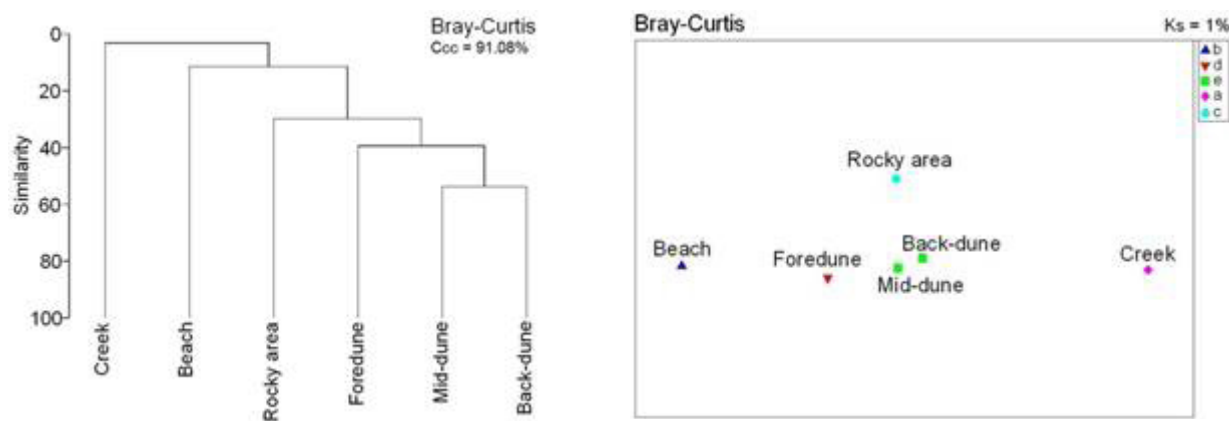
(a) Jaccard index. Native + synanthropic species.



(b) Jaccard index. Native species.



(c) Bray-Curtis index. Native + synanthropic species.



(d) Bray-Curtis index. Native species.

Figure 5. Floristic similarity with and without synanthropic species. Left: Dendrograms. Right: Scatter plot graphs. Ccc - Cophenetic correlation coefficient; Ks - Kruskal's stress.

Considering only native species, richness was reduced, especially in the most synanthropic habitats: in the back dune, diversity was reduced by almost two-thirds and in the mid-dune by nearly half. In the rocky areas, diversity was somewhat reduced by the presence of a significant number of alien species. In the creeks, richness and diversity were drastically reduced. In the fore-dune, the change was slight, and on the upper beach, the situation did not change because there was no synanthropisation.

Discussion

Our results showed a synanthropisation rate in the area of 51%, which varies between habitats, with a null value on the upper beach and 63% on the back dune. In coastal areas of Ukraine, Dubyna *et al.* (2010) obtained a synanthropisation rate of 37.1% (20.9% apophytes, 16.2% alien), and Kolomiichuk & Maltseva (2014) 44% (24.5% apophytes, 19.5% alien). Valcheva *et al.* (2019) recorded 27.1% of synanthropic species (17.4% weeds, 9.7% alien) on the Bulgarian coast.

The percentage of alien plants reached 18%. Sobrino *et al.* (2002) recorded 20% of alien species in coastal zones of NE Spain, a very similar value. Giulio *et al.* (2020) recorded an average of 7% of kenophytes in coastal dunes in Europe and Tordoni *et al.* (2018) a 8.6% on the Italian Adriatic coast, while in Australia naturalised alien species reach up to 59% of coastal dune flora (Batianoff & Franks, 2000). Szwed & Sýkora (1996) detected a majority of apophytes on roadside verges in coastal dunes in the Netherlands. Tordoni *et al.* (2021) highlight those anthropogenic factors, such as gross domestic product, are positively associated with alien species richness in coastal areas. The area studied is a popular summer resort (like most Spanish coasts), which implies heavy investment in urbanisation and landscaping and high tourist pressure, which explains the high percentage of alien species.

In Spain, the dominant origin of alien plants is in North and South America (Sanz *et al.*, 2004). In the

coastal areas of northern Spain, 56% of the species come from America and only 7% from Africa (Campos *et al.*, 2004), and on the Italian coast, American species also dominate (Acosta *et al.*, 2007; Del Vecchio *et al.*, 2015). However, the study area, only 30 km from the African coast, has a drier and warmer climate than northern Spain or most Italian coasts. This could justify the high percentage of African species recorded here (41%). Giulio *et al.* (2021) indicate that alien plants from Africa might have a slightly higher invasion success in coastal dunes in Europe, although species from North America and the Mediterranean-Turanian region dominate at the European level (Giulio *et al.*, 2020).

The main paths of the introduction of alien plants in Spain are gardening (48%), agriculture (18%), unintentional introduction and weeds (31%) and forestry (3%) (Sanz *et al.*, 2004). In northern Spain, these percentages are quite similar (Campos & Herrera, 2009), with a higher weight of unintentional introduction (44%) and a lower rate of garden plants (32%). In our study area the weight of gardening is much higher (59%), and that of agriculture lower (8%); this is explained because the area borders on landscaped areas, which makes it easier for species to escape from the gardens and become feral. Batianoff & Franks (2000) point to the dumping of garden waste as a source of alien plant introduction in coastal dunes, a situation that may be occurring in this area. The vast majority of species were kenophytes, a result consistent with that obtained by Del Vecchio *et al.* (2015) in Italy.

In the studied area, only *Arundo donax* competes with the natural vegetation. However, there are some aggressive invasive species, which are not currently common, but whose populations could skyrocket if left unmanaged. There are also apophyte species that compete with the natural vegetation, although not aggressively (e.g. *Dittrichia viscosa*, *Plantago coronopus*, *Plantago bellardii* or *Scolymus hispanicus*). Acosta *et al.* (2006) analysed the flora of coastal dunes in Italy according to functional groups, finding that invasive alien species were mainly annuals, which mature quickly, or perennials often with stolons or rhizomes that allow for

rapid spread, two strategies that enable them to occupy coastal habitats.

Asensi *et al.* (2016) identified 26 alien species on the southern coast of Spain (including the study area); about half of them have also been detected in this study, but in addition there are 15 new species now detected. This could be partly because they have gone unnoticed, as this study is more local but more comprehensive, but also probably (at least in some cases) because of their recent colonisation.

Anthropopressure favours synanthropisation, making it difficult to identify the plant communities of coastal dunes (Sarmati *et al.*, 2019). In the study area, it is still possible to differentiate the main natural habitats, although the presence or even dominance of some apophyte species makes the interpretation of some vegetation relevés difficult.

On the upper beach and on the foredune, trampling causes a loss of vegetation cover and richness, which is even greater on the beach as a result of mechanical cleaning (Nordstrom *et al.*, 2000) and the construction of bars and terraces. However, there is no significant synanthropisation. The harsh ecological conditions limit the colonisation of ruderal plants (Malavasi *et al.*, 2016); in the study area this is demonstrated by the absence of synanthropic species on the upper beach, and their scarcity on the foredune, where they are also concentrated in the area closest to the mid-dune. In Italy, Acosta *et al.* (2009) note that the upper beach has a lower richness, as in this case, but at the same time, the highest rarity values and the highest proportion of endangered species.

Pedestrian traffic is concentrated on the main paths, where wooden walkways have been constructed. Outside these paths, there is no appreciable loss of vegetation cover, partly because it is already moderate on the foredune and mid-dune. Some studies indicate that the effects of trampling on Mediterranean dunes are temporary, with good potential for recovery, although not those of vehicle traffic (Kutiel *et al.*, 2000; Farris *et al.*, 2013). Rickard *et al.* (1994) report a high recovery potential for pioneer dune communities in South Africa but a low recovery potential for shrubs, which is also applicable to this area; analysis of historical aerial photographs of the area showed that there has been virtually no recovery of shrub cover for decades.

In mid-dune, tracks were built for beach service vehicles (especially quads), taking advantage of the gentle relief, the greater compactness of the terrain and the absence of scrub. This has increased synanthropisation, and the proliferation of species like *Echium gaditanum*, *Scolymus hispanicus* and *Arundo donax*. The back dune is the area with the greatest synanthropisation and presence of alien species.

Carboni *et al.* (2010) indicated for Italy that the high levels of invasion in the transition dune could be partly explained by the higher propagule pressure in this area. However, Bazzichetto *et al.* (2018) applied a complex assessment model, finding that invasion does not occur homogeneously across the coastal landscape but occurs where the combined action of propagule

pressure and abiotic and biotic factors is favourable for the establishment of the invader.

In the study area, a clear differentiation of habitats with distance from the coastline was detected, consistent with the results obtained by Bazzichetto *et al.* (2016) in Italy, as well as an increase in diversity and synanthropisation inland. The influence of wind and soil properties on coastal vegetation varies between areas, with the former or the latter being more important (Fenu *et al.*, 2013; Ciccarelli, 2014). The study area is among the windiest in the Mediterranean region, constantly subjected to westerly or easterly winds, which justifies the dominant influence of wind on vegetation, and the strong inland gradient.

The synanthropisation of the area has led to an increase in species richness, which has doubled; approximately half of the species recorded are native and half are synanthropic. This result is consistent with those recorded in other regions, such as Denmark (Brunbjerg *et al.*, 2015) or Italy (Prisco *et al.*, 2016). Diversity is an indicator that should be handled with caution, considering at the same time the synanthropisation of the vegetation. In the study area, the mid and back-dune were very diverse, but due to the presence of numerous species not native to these habitats, favoured by human action.

Anthropopressure produces a synanthropisation of coastal vegetation which, in this area, results in an increase in richness but also in a loss of naturalness and a risk of biological invasions. The fragility, richness and ecological value of coastal ecosystems, together with their reduced surface representation, make it necessary to adopt measures for their conservation, which must take into account the problem of synanthropisation.

Firstly, it is important to protect the entire dune system, regardless of its species richness, as there are areas of low richness and high uniqueness, such as the upper part of the beach (Acosta *et al.*, 2009; Kuroda & Sawada, 2019). The declaration of vegetation micro-reserves – a protection figure that already exists in several regions of Spain – in well-preserved coastal areas, such as the one studied, would be highly recommended.

In the management of coastal dune systems, it is important to establish vegetation recovery periods (Lemauiel & Rozé, 2003). Fencing of dune systems reduces trampling, a passive recovery system that increases vegetation cover and the richness of protected areas (Acosta *et al.*, 2013). Symbolic fencing is preferable for controlling pedestrian access because it is less visually intrusive and does not alter the natural wind transport regime (Nordstrom *et al.*, 2000; Grafals-Soto & Nordstrom, 2009). Rerouting pedestrian traffic is also interesting (Nordstrom *et al.*, 2000), a measure that has already been adopted in the study area by constructing wooden pedestrian walkways. However, uncontrolled access to the beach still exists and should be regulated. Vehicle traffic should be limited to the intertidal zone to avoid the destruction of vegetation and dunes (García-Mora *et al.*, 2001).

A major problem is beach cleaning and the placement of bars and terraces. García-Mora *et al.* (1999) indicate

that beach management in Spanish tourist resorts is oriented towards sand sieving and gardening of embryo dunes, affecting native species and favouring kenophytes. Nordstrom *et al.* (2000) point out the need to modify beach cleaning procedures. Mechanical cleaning is destructive for the vegetation and should therefore be limited to the bare beach, with manual cleaning of the upper area. In addition, beach bars and terraces are often located precisely in the upper part of the beach, destroying its vegetation and the embryo dunes; it would be desirable to relocate them inland, outside the dune system, or at least away from the upper part of the beach, with lighter mobile installations.

The use of alien species in areas adjacent to coastal dunes should be restricted (Nordstrom *et al.*, 2000), especially those with proven or potential invasiveness.

There are several experiences of eradication of invasive plants in coastal dunes, especially *Carpobrotus*: Buisson *et al.* (2021) showed successful eradication results; Andreu *et al.* (2010) analysed their manual removal in Andalusia (including the study area), noting that although the density was greatly reduced, repeated uprooting treatments were required; Lazzaro *et al.* (2020) noted the efficacy of using glyphosate, a controversial herbicide (it is authorised in the EU until 15 December 2022, and an extension is under evaluation). However, eradication of alien plants may also encourage synanthropisation. Kim *et al.* (2019) noted for Korea that invasive species removal was costly and, if not done very carefully, could even increase the initial invasion. Novoa *et al.* (2013) found that dunes regenerated after *Carpobrotus* removal were occupied by opportunistic ruderal species, which competed with native dune plants. Eradication decisions should be based on the importance of the invasion, weighing the benefits and risks.

Conclusions

Coastal dunes have a high ecological value but are often overexploited by beach tourism. A major problem with these areas is that, although they occur along most coasts, a considerable length in Spain, they are of small width, and the vegetation has often been removed by urban and tourist development.

In addition to the physical destruction of vegetation, another important problem is synanthropisation, both through the colonisation of alien species, sometimes invasive, and apophyte species favoured by human action. The colonisation and expansion of non-native species in the coastal ecosystem affect its naturalness and even the presence of some native species as a result of competition for space.

This study analyses the degree of synanthropisation of vegetation along a stretch of the coastline of southern Spain. Half of the species inventoried were synanthropic, two-thirds of them apophytes (mainly ruderal species and weeds), and the other third alien species (mostly from gardens adjacent to the coastal zone). The degree of synanthropisation varied according to habitat, ranging from zero on the upper beach to about two-

thirds on the back-dune, with a marked increase from the beach inland. Although only one invasive species, *Arundo donax*, was detected, there are several others with high invasive potential, whose populations could grow rapidly if left unmanaged.

Comparing the orthophotos from 2001 and 2020, it can be observed that there has been no appreciable loss of vegetation in those 20 years. However, the degree of synanthropisation is high, especially in the back dune, and several alien species that only grow in gardens bordering the coast have now also been detected in coastal habitats. Therefore, although protection against urban development has been effective in physically maintaining the vegetation, it is not preventing the progressive entry of alien species, some of them with high invasive potential.

Measures must be taken to protect coastal vegetation from destruction and synanthropisation, especially from the spread of invasive species. Including these areas in a legal protection scheme, and applying specific management, conservation and monitoring measures would be desirable, as mere nominal protection is not effective in guaranteeing their conservation (Sperandii *et al.*, 2020). Other desirable measures are: regulating access to avoid trampling; avoiding vehicle traffic; symbolic fencing; respecting regeneration periods; avoiding mechanical cleaning of the beach and the placement of bars and terraces on the upper part of the beach; or the eradication of invasive species, carefully assessing their advantages and disadvantages to avoid unwanted synanthropisation as a result of these actions.

Conflict of interest

None.

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Supplementary Material

Table S1. Plant occurrence in the studied habitats.